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Designing of Soil-Concretes Using the Kursk Magnetic Anomaly Technogenic Raw and Waste-Lime-Based Binder for Reinforcing of Road Pavements Subgrades

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Abstract: The classification of technogenic raw materials according to the extent of their transformation in the process of technogenesis is developed; the efficient fields of using of mechanogenic waste from Lebedinsky mining complex of Kursk magnetic anomaly with account of its technogenic transformation extent have been determined. The mechanism of formation of technogenic raw microstructure is suggested, which implies microstructure self-organizing that consists in regeneration (spontaneous recovery) of the initial coagulative and crystallizational microstructure, destroyed by mechanical impacts. The compositions of soil-lime mixture on the basis of clay technogenic raw material of KMA (loose strip) are developed for stabilizing the subgrades of road pavements. Also the influence of two-component soil-lime mixture: lime-containing binder and cement is studied on the total value of yield compressive strength. An empirical mathematical model of soil-concrete strength development process is suggested, which allows solving the problems of designing mixture with required strength of soil-concrete. The character of interrelation between the initial technogenic raw material microstructure and microstructure formation processes in soil-concrete has been determined. It is considered the kinetics of microstructure formation of soil-concretes based on clay and sand technogenic raw materials,as well as strength characteristics development of soil-concretes in time are studied.

Key words: Technogenic raw materials · Loose strip (LS) · Waste of the grinding-sorting factory · Stabilizing soil with binders · Soil-concretes · Road subgrades

INTRODUCTION

By the beginning of the third millennium the human activity has become commeasurable in its scale with geological processes. It's enough to remark, that 4,5 billion tons of raw rock materials are processed in the world every year and less than 10 % of them are used. The fields of efficient application of waste, are usually not determined. At the same time about the same amount of raw material is annually excavated for needs of building materials industry.

Every year over 2 thousands ha of land are allocated for waste storage, including valuable agricultural lands, which also affects the environmental situation of regions in Russia. This problem is urgent for Belgorod region where there is situated a number of Kursk magnetic anomaly deposits (KMA). A great amount of waste is produced at Lebedinsky and Stoylensky minings, where tens of millions of cubic meters of technogenic raw are generated every year. The most bulk is mechanogenic waste, which can be efficiently used in road building.

Both Russian and foreign researchers have made a substantial contribution into solving the problem of using industrial waste for producing the high-performance building materials [1–8].

Taking into account the state of raw material supplies base, requirements to the quality of roads and economic parameters, it seems that nowadays and in the foreseeable future the mostly wide application in road building can be obtained by soil-concretes – composite materials on the base of industrial waste, containing the minimum of scarce and expensive binders and additives [9].

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The advantage of soil-concretes, which allows their efficient use in road surfacing constructions is the forming of strong solid slab, which possesses sufficient bearing capacity and rigidity to carry the mobile load impact without destroying as well as distribute it to a large area of underlying layers. The soil-concrete layers of road surfacing can easily match the scree, gravel or sand layers.

The implementation of building the stabilized pavement layers on the base of technogenic materials will allow broadening the raw materials basis for producing od road soil-concretes and reducing the environmental impact in the areas of waste storage. In this regard the aim of this research was improving the efficiency of road building by using the ÊMÀ technogenic raw with account of its genetic features.

Methodology: The research, carried out in the course of this work, was performed using the up-to-date methodology and material and technical basis, which allowed obtaining representative and consistant results.

One of the basic methods of research was studying the microstructure of initial raw components and synthesized components with scanning electron microscope. The microphotography was performed using a hardware-software system, including a high-resolution scanning electron microscope (SEM) "Hitachi-S-800", combined with a PC. The images were taken by secondary electron emission. To obtain a high-quality SEM image the method of vacuum thermal spraying of samples was used. The spraying was performed with gold film with 10 nm of thick.

Basic Part: The analysis of KMA technogenic raw materials (Fig. 1), including mechanogenic, pyrogenic and, in a lesser extent, chemogenic and biogenic formations, has shown, that the most bulk waste materials, which can be used for building of soil-concrete beds of road pavements, are: clay loose strip (LS) and sand waste of the grinding-sorting factory (GSFW) of Lebedinsky mining.

Research of composition and properties of the technogenic raw materials allows concluding the following: GSFW is presented by grey sand-clay composition, containing 2–4 % of clay component and the rest is sand fraction, mostly quartz sandstone debris. The loose strip consists of 50–55 % of finely-dispersed clay component and 45–50 % of sand fraction. The clastic (fragmentary) material is unrounded and uniformly distributed in the bulk. It is presented mostly by flattened flaky particles to 5 mm. According to road soil classification and physical and mechanical properties of technogenic materials the loose strip refers to loam soils with I_p=13 and grinding-sorting factory wastes are sandy soils with $M_{кр}$=2,96 [10].

Analysis of structure and material composition of the waste under research, as well as genesis and technogenesis correspondence rule when production of building materials with minimum energy consumption allow determining the efficient fields of their use (Fig. 2).

It is established, that at using soils with the same plasticity index (I_p) and the same sand grain content, i.e. belonging to one and the same type according to the road classification, the samples of technogenic soils have different performance characteristics and different influence on the processes, going on at their use as raw components for road-building materials. So, these parameters of raw materials are essential, but not sufficient when developing the soil-concrete compositions. As well as the mineral composition of raw materials and microstructure parameters play crucial role in the structure formation process.

According to scanning electron microscopy data GSFW is presented by loose polyfractional mixture with grain size from 8 to 220 µm. There are easily observed quartz particles of various genetic types, which are confirmed both by grain morphology and morphology of their surface [11].

In shape there are distinguished rounded, close to isometric, sedimentary quartz particles (Fig. 3, a) and angulated (Fig. 3, b), anisometric, often flaky quartzitic sandstone debris. The quartz grains of these genetic types differ also in surface morphology. The sedimentary quartz has the spongy surface, typical for sand-grains, having gone through the stages of weathering and transportation. The metamorphogenic quartz has a strongly pronounced shell-like fracture. All particles are covered with "jacket" of the more finely dispersed substance of the same polymineral composition.

Besides quartz grains of various genetic types there are flat mica flakes, columnar amphibole particles, which are easily discerned by crystal habit.

A considerable part of polydisperse grains in GSFW (to 125 µm) are microaggregates of polymineral clastic phases (Fig. 4), which are bonded both by electrostatic forces and coagulative bonds, provided by a small quantity of clay minerals. This results in lowering the homogeneity of mixtures containing GSFW and inadequate data concerning fineness modulus, which affects the composition calculation at a later stage and, as a result, leads to overconsumption of binder.

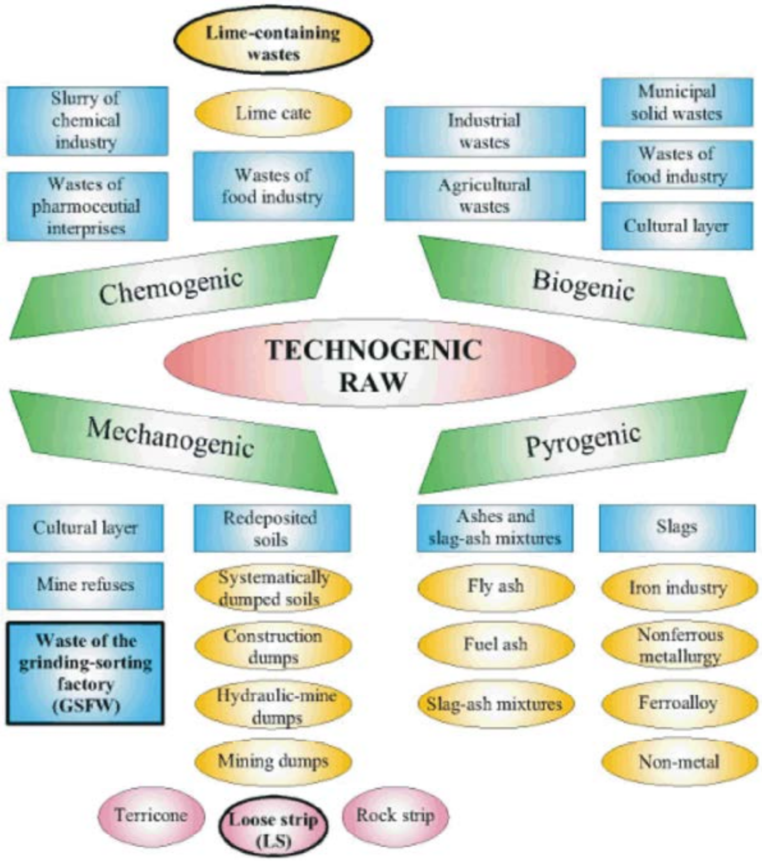


Fig. 1: Types of KMA technogenic raw materials

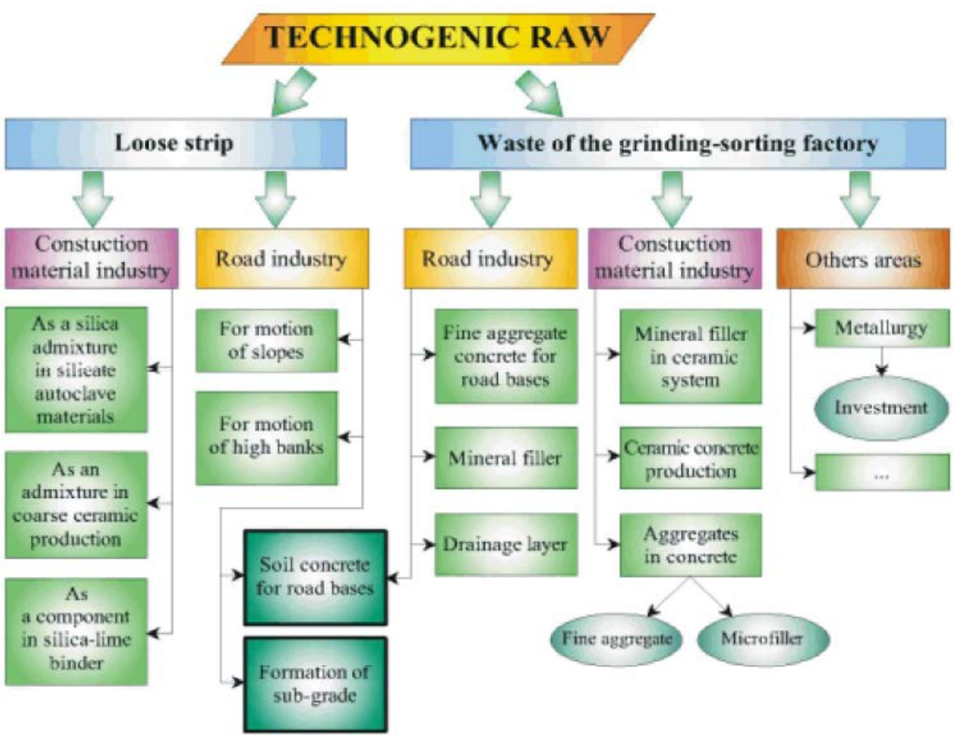
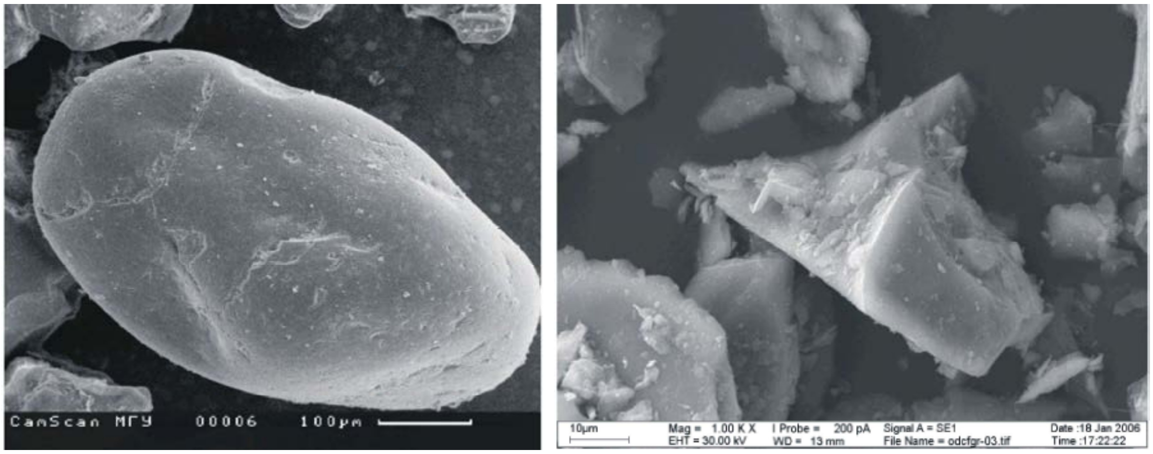
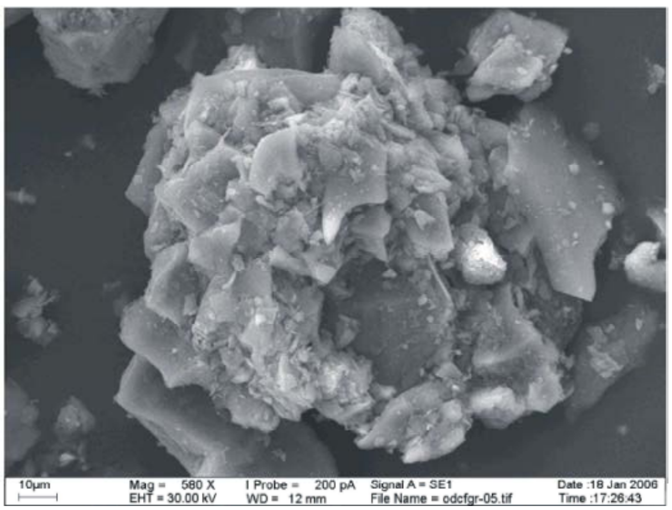


Fig. 2: Fields of efficient application of technogenic materials from Lebedinsky mining



(a) (b)

Fig. 3: Morphology of quartz grains of various genetic types in GSFW:



a – rounded particles of sedimentary genesis, b – clastic phases of quartzitic sandstone

Fig. 4: Polymineral aggregates in GSFW

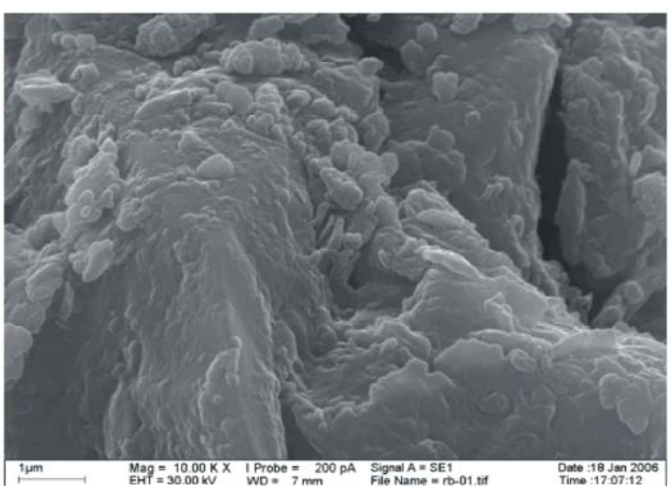


Fig. 5. The structure of loose strip bulk

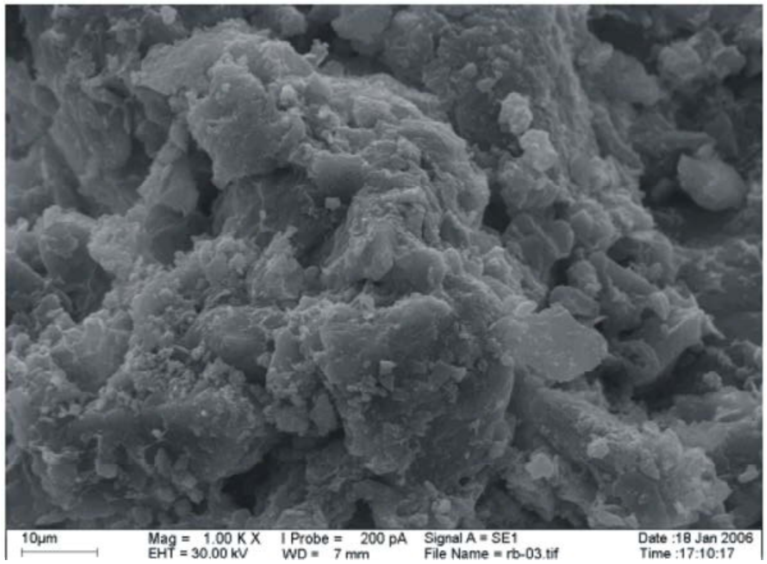


Fig. 6: The skeletal microstructure of loose strip

The characteristic features of various genesis quartz grains presence is the large extent of clastic particles aggregation (quartzitic sandstone debris) and almost complete isolation of rounded quartz particles from each other.

The considerable content of clay matter in LS results in forming in the disposal area during its storage of rather a compact composite material with yield compressive strength of 1,2 MPa at humidity of 14 %. It has the natural porosity, due to compaction by gravity at storing waste in dumps. The pores are of anisometric shape. Due to sufficiently loose structure of the basic matrix at the microlevel all pores can be considered to open. The size of pores can be of a wide range – from 200 to 0,3 µm.

The skeletal component of technogenic raw has a polydisperse polymineral composition with inclusions of isometric, though angulated, quartz grains, elongated columnar well-faceted amphibole crystals and flat mica flakes.

The pulverescent quartz particles are covered with clay "jackets" and contact the other particles through thin chains of clay particles – clay bridges, which are coagulative contacts by their nature, as well as contacts between clay particles in the bulk of technogenic raw component.

The bulk of technogenic stuff, consisting mostly of compacted clay minerals, has the close soil-like texture (Fig. 5). All over the surface there are flakes of clay particles to 1 µm in size, loosely bound with matrix. According to the shape of grains we can make the conclusion that hydromica and kaolinite predominate in the matrix of this soil.

According to microscopic structure, interconnection and spatial arrangement of particles, the loose strip has the skeletal microstructure (Fig. 6).

So, it has been determined, that the waste dumps of Lebedisky are presented by technogenic clay and sand materials of mechanogenic origin, which can be described as complex-structured polymineral polygenetic system with relic and newly formed structures, which has no counterparts among natural formations in its set of properties.

We have suggested the mechanism of clay technogenic component microstructure formation, which consists in microstructure self-organizing, that is regeneration (spontaneous recovery) of the initial coagulative and crystallizational microstructure, destroyed by mechanical impacts.

The self-organization phenomenon is conditioned by high chemical activity, high dispersity, crystallochemical structure features and inorganic composition of clay minerals. The self-organizing of technogenic clay raw materials microstructure results in technogenic lithogenesis, which takes place in waste dumps at technogenic deposits formation [12].

According to the mechanogenic formation conditions of material and taking into account the secondary technogenic impacts with total microstructure rupture and forming uncompensated charges of surface; microstructural characteristics and mineral composition, existing methods of soil stabilization and the region's resource potential, we can state the necessity to develop an integrated method of stabilizing with inorganic binders, by using a stabilizing additive – a lime-containing

Table 1: Composition and properties of soil concretes*

Type of the initial soil	Content of binders, %		The yield compressive strength (ÌPa) of samples after (days) (hardening in damp / dry-air medium)			
	Lime-containing binder (LCB)	Cement	1	3	7	28
Loose strip	5	3	3,20 / 7,60	3,70 / 8,50	4,10 / 10,0	4,40 / 10,90
	10	3	3,00 / 7,00	3,40 / 8,10	3,70 / 9,80	4,25 / 11,10
	15	3	1,70 / 5,00	1,90 / 5,90	1,90 / 7,90	2,35 / 8,90
	5	5	3,60 / 7,80	4,10 / 8,90	4,65 / 10,70	5,05 / 11,60
	10	5	3,60 / 9,20	4,40 / 9,60	4,75 / 10,30	5,35 / 11,30
	15	5	2,10/ 7,00	2,40 / 7,60	2,60 / 8,90	2,90 / 10,70
	5	10	4,00 / 10,60	4,70 / 12,00	5,20 / 14,10	6,8 / 15,60
	10	10	3,40 / 8,40	3,90 / 9,30	4,20 / 10,90	4,70 / 13,10
	15	10	2,00 / 7,60	2,20 / 8,50	2,40 / 9,70	2,70 / 11,20
Grinding-sorting factory waste	–	3	1,00 / 1,75	1,20 / 2,30	1,50 / 2,80	1,75 / 3,60
	5	3	0,80 / 1,60	1,10 / 2,35	1,30 / 2,750	1,65 / 3,55
	10	3	1,10 / 2,20	1,30 / 2,65	1,60 / 3,50	2,10 / 5,25
	15	3	1,00 / 1,95	1,20 / 2,45	1,75 / 3,50	2,20 / 4,65
	–	5	0,90 / 1,95	1,25 / 2,45	1,50 / 3,10	2,00 / 4,05
	5	5	1,20 / 2,40	1,50 / 3,15	2,15 / 4,10	2,60 / 5,35
	10	5	1,20 / 2,95	1,60 / 3,75	1,80 / 4,65	2,10 / 5,80
	15	5	0,90 / 3,25	1,10 / 4,30	1,85 / 5,05	1,95 / 6,05
	–	10	1,90 / 3,80	2,30 / 4,60	2,80 / 5,65	3,30 / 6,60
	5	10	2,50 / 4,90	3,50/ 7,00	4,20 / 8,95	5,5/ 10,00
	10	10	2,00 / 4,75	2,30 / 6,65	2,70 / 7,95	2,90 / 9,30
	15	10	1,60 / 4,05	2,10 / 5,20	2,30 / 6,50	2,7 / 7,55

component for the subsequent addition of cement when obtaining road-building soil-concretes both on the basis of clay (LS) and sand (GSFW) technogenic raw materials.

The formulations of soil-lime mortar based on loose strip for strengthening the earth bed of road pavements are designed. The analysis of synthesized samples' strength indices showed, that the optimum amount of waste lime, added to the technogenic clay material (LS) is 5 %, which allows obtaining the strength indices of 4,5 MPa in cement-free samples.

To determine the optimum soil-concrete compositions there were synthesized samples with different content of binders (Table 1). The compacting pressure was 15 MPa, which corresponds to the pressure of a 10 ton road-roller.

There was researched the influence of two components: lime-containing binder and cement in soil-lime mortar was researched on the total value of yield compressive strength. There is suggested an empirical mathematical model of the soil-concrete strength gain process, which allows solving the problems of proportioning the considered components for obtaining the desired strength of final product – soil-concrete for building and the stabilized road subgradesat the fixed value of plasticity index and a stated genetic type of the raw material [13, 14].

$$R^{p}_{compress}(C_{CEM}, C_{LIM}) = \sum_{k=0}^{N}\sum_{m=0}^{N} b_{k(N+1)+m} C^{k}_{CEM} C^{m}_{LIM} ,$$

where C_{CEM} and C_{LIM} – concentration of cement and lime-containing binder respectively, b_i – required regression equation coefficient, $i=k(N+1)+m$; N – power coefficient; k, m – indices.

It should be pointed out, that the model provides rather an accurate description of the process studied, which is proved by comparative analysis of design and experimental data (Fig. 7). At applying the suggested dependences for other genetic types of raw materials it is necessary to introduce coefficient, taking into account the influence of mineral composition on soil-concrete structure formation processes.

The concept of continuous strength gain of soils, processed with lime-containing binder, has great importance for these materials' evolution in road surfacing constructions. The strength gain helps compensating the fatigue effect from repeated loads and also can conduce to "healing effects" against the impact of damping-drying and freezing-thawing cycles [15].

The strength gain of soil-lime composite in the course of time is connected with pozzolanic reactions, which results in the generation of new formations, cementing the technogenic soil. At the initial period of hardening the

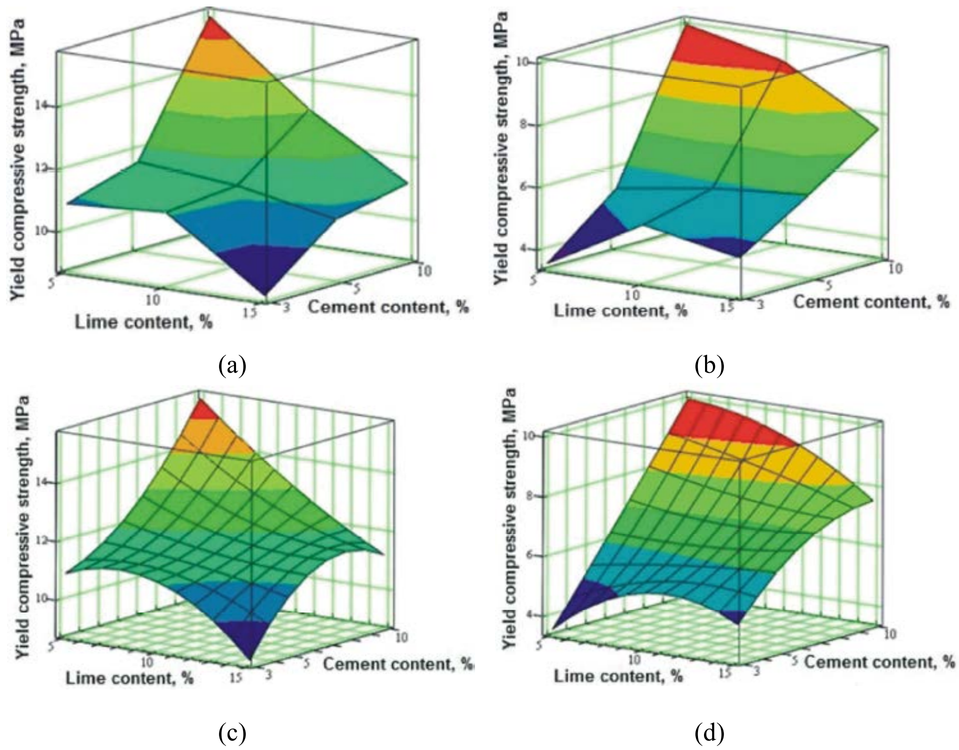


Fig. 7: The comparative analysis of designed (*a, b*) and experimental (*c, d*) data of yield compressive strength for LS (*a, c*) and GSFW (*b, d*)

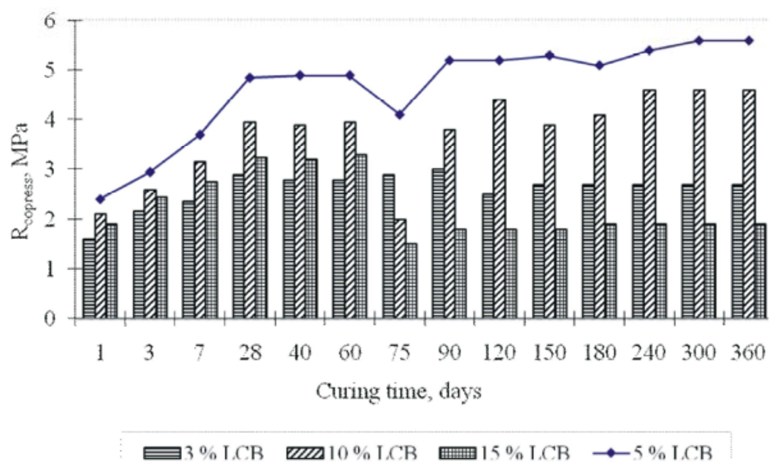


Fig. 8: Evolution of strength at the continuous hardening of loose strip with lime-containing binder samples

strength of samples with the optimum binder content amounts reach to 2,4 MPa (Fig. 8). At the good initial reaction the strength gain is observed during 28 days. This is connected with the formation of gel-like globules on the surface of clay particles and hardening of the sample's structure. Then, during 60 days the attenuation of strength alterations and further gellation is observed.

The strength reduction on the 75^{th} day is connected with the initial crystal formation and the sample's structure decompaction processes. The next stage (6–12 months) is characterized by certain stability; no noticeable reduction of the material's strength in the humid-air state is observed at this stage.

The comprehensive research of microstructure characteristics of KMA technogenic raw materials and soil-concretes on their base has allowed retracing the inheritance of structure formation kinetics in natural and technogenic soils and composites on their base, which

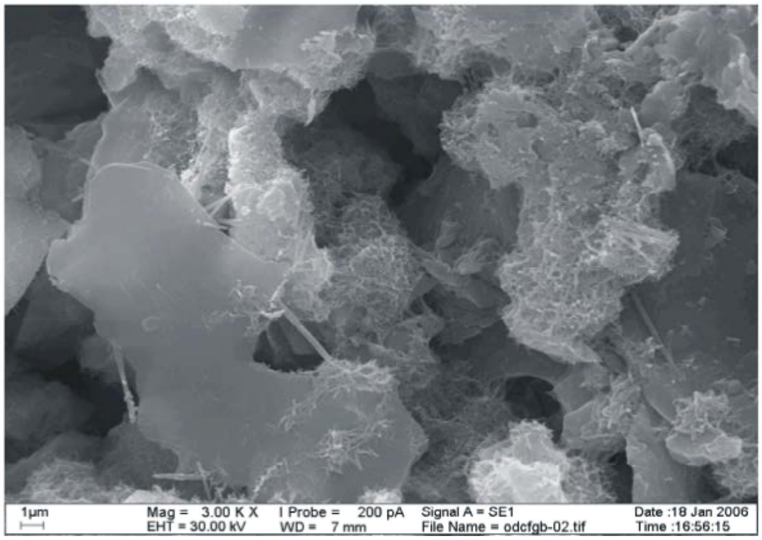


Fig. 9: The laminar quartz debris of atypical morphology, covered with acicular formations (on the base of GSFW)

makes it possible to design structures when obtaining road-building materials with pre-determined properties and with account of mineral composition variability of the source raw materials. In view of the above a mechanism of structural transformations at receiving soil-concretes in system "technogenic raw stuff – lime-containing binder – cement – water" was suggested which allows synthetizing structures with pre-determined properties in the postgenetic (operational) period.

There are discovered finely-dispersed quartz clastic phases of atypical (micaceous) morphology (Fig. 9), characteristic of finely-dispersed quartz of metamorphogenic origin. Judging by the contact area of new formations with the base, a quartz plate, the latter one has good adhesion to the newly formed substance.

For the first time the microstructure alteration kinetics of soil-concretes on the base of clay and sand technogenic materials has been researched with SEM-microphotographs at the age of 28 days, 1 year and 3 years. The formation of network out of immature X-ray amorphous matter with pronounced oolith-like component parts, connected in the form of chains, within longtime hardening periods in soil-concrete, based on sand technogenic raw stuff (GSFW) is observed (Fig. 10). It is proved that during the postgenetic period in material, based on clay technogenic raw stuff (LS), newly-formed crystals, having the well-pronounced shape and faceting are generated. The new formations assume the pyramidical shape (Fig. 11), which cover a pseudoglobular structure in a form of a druse.

The absence of these types of structure in 28-days-old samples indicates that the dissipated micropseudoglobular substance is a postgenetic formation. The size of single globules is no higher than 200 nm (Fig. 12), which indicates the X-ray amorphism of such structures (in Fig. 13 the nanoscale structure of single globules is shown). This prevents fulfilling the unambiguous diagnostics of their composition. Though, on the account of these new formations' universal distribution in 1-year-old and 3-year-old LS-based samples, their absence in the similar GSFW-based composite, initial clay raw components and 28-days-old samples, as well as in the used binders (the lime-containing component and cement), we can make suppositions about their nature.

These pseudoglobular formations are nucleuses (crystallization centers) for the subsequent formation of calcium hydrosilicates and hydroaluminates – products of cement hydration in system "clay minerals – LCB – cement – water". The main factor, causing such a wide dissemination of pseudoglobular matter aggregates all over the soil-concrete sample, is the presence of clay phase. The imperceptible influence of sand fraction minerals, including quartz, on these processes is caused by the absence, as it was mentioned above, of such structures in GSFW-based samples, where the quartz component predominates over the clay phases.

The clay matter due to its specific nature is involved in such processes as calcium absorption, colloid coagulation, interaction of silica and alumina with calcium ions and $Ca(OH)_2$ molecules with the formation of additional cementing substance, which results in forming of gel-like products [16].

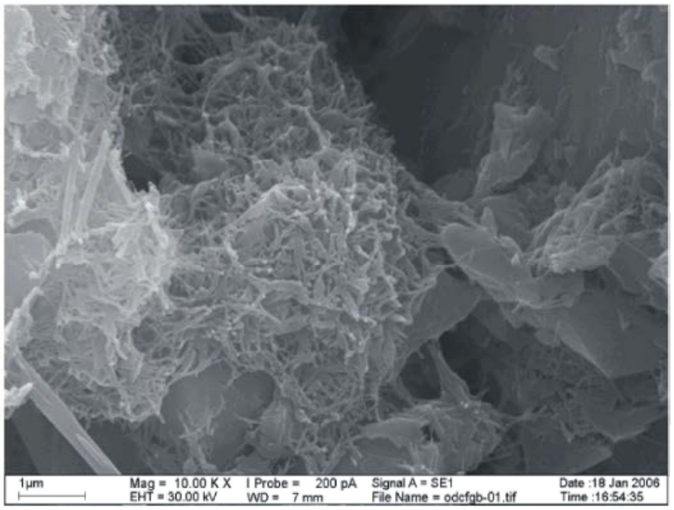


Fig. 10: The network of newly-formed oolith-like substance on the surface of clastic phases in the GSFW-based soil-concrete

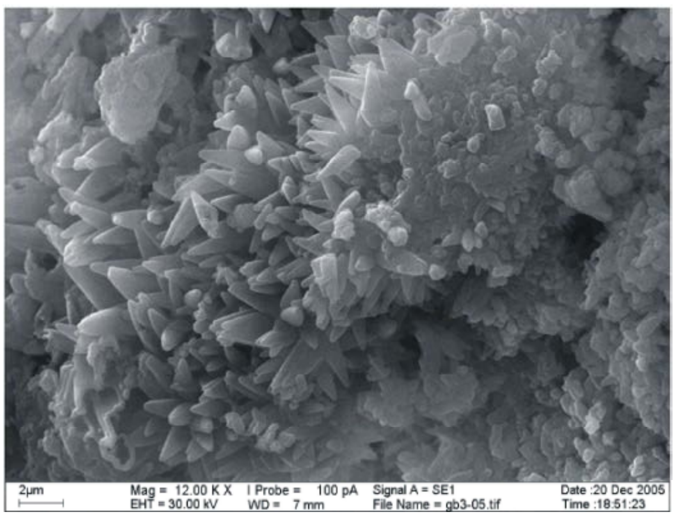


Fig. 11: The pyramidical formations in the LS-based soil-concrete at the age of 3 years

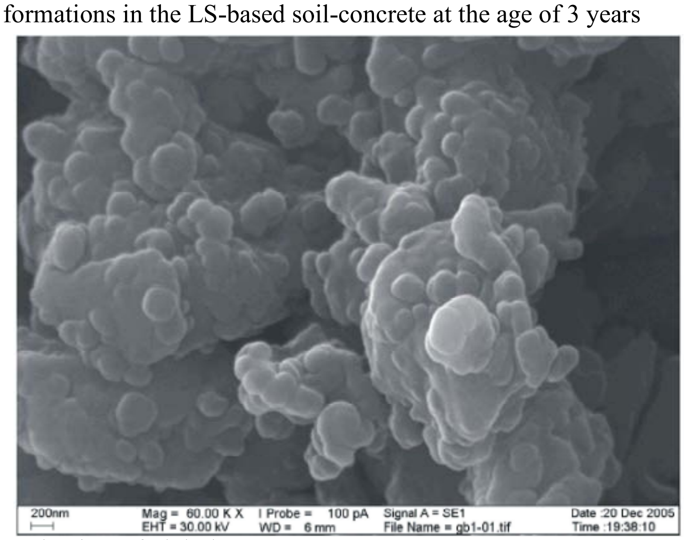


Fig. 12: The general nanoscale view of globular mass

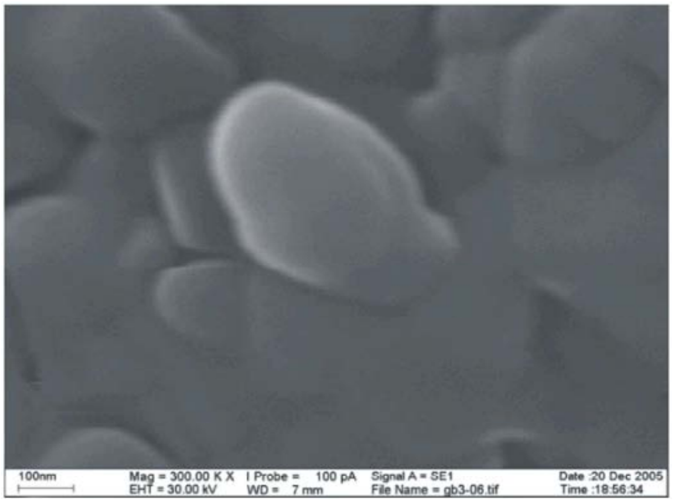


Fig. 13: The nanoscale view of separate globules of the matrix in LS-based soil-concrete

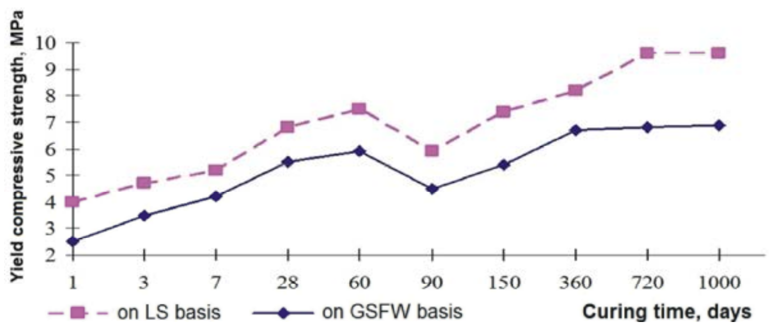


Fig. 14: Kinetics of strength alteration of optimal-composition soil-concrete at continuous hardening

The differences of chemical and mineralogical medium of GSFW-based and LS-based materials, in which the newly formed hydrosilicates and hydroaluminates are generated and grown and $Ca(OH)_2$ is dissolved and precipitated results in the difference of the newly-formed phases composition, which is proved by their morphology and crystal habit (Fig. 10, 11).

In the process of further strength gain the structure of the system, formed by the newly-formed matter, undergoes serious alterations. On one hand, it becomes more homogeneous; voids are occluded, separate fragments of structure coalesce, which is the reason for the hardening of the synthesized composite. On the other hand, the morphology of the matrix's components is cardinally altered.

The structure decompaction period between 60–90 days (Fig. 14) is determined. The microstructure decompaction is conditioned by the pressure of new formations on pore walls and by the breaking of contact between structure-forming components of the system. This results in decrease of strength characteristics of the composite in general. The subsequent strength gain is connected with the secondary consolidation of the structure. The dissolved matter in the composite fills microcracks, forms the enabling environment for nucleation and decrystallization results in "healing" the composite's microstructure defects. It promote to the augmentation of strength to its maximum value (preceding its reduction) and its further growth. The variation of strength within this period amounts to 22 % [15].

In such a way, it is proved, that during the longtime damp hardening of soil-concrete, based on mechanogenic technogenic raw material, the chemical interaction processes continue, that leads to the concreting of the synthesized composite's microstructure and as a result to the strengthening of road-building material.

By adding 10 % of Portland cement to the soil-lime composite a technogenic-based soil-concrete was obtained, having: ultimate compression strength up to 15,6 MPa for LS-based soil-concrete and 10 MPa for GSFW-based soil-concrete (with account of technological coefficient – 0,89 and 0,91 respectively); freeze-proof factor of 0,81 for LS-based soil-concrete and 0,74 for GSFW-based soil-concrete; waterproof coefficient of 0,64 and 0,52 respectively. The formulations, designed on the base of Lebedinsky mining technogenic raw materials allow using synthesized composite for building of subgrades for roads of III–IV categories.

CONCLUSION

It is commonly known that road building is one of the major natural resources consumers. Nowadays no less than 50 % of costs at building motorways are the cost of building materials. So, the lessening of demand for expensive materials as well as solving the problems of resource-saving is one of the most urgent problems. In this regard energy-saving and resource-saving technologies implying the usage of local raw material resources are the most appropriate ways. Using for this purpose the technogenic raw materials i.e. waste products of various industrial enterprises, mining and concentration plants will also allows reducing the negative impacts of technogenic deposits on the environment.

The material composition of technogenic raw determines, finally, the whole variety of these material building properties. Therefore, by affecting the phase composition of such materials, varying the characteristics of phases and the nature of their interaction, we can achieve the artificial changing of technogenic materials' building properties in the required direction. In this regard designing soil-concretes is the simplest way of using these materials and achieving the required effect i.e. with no loss in strength and performance characteristics of road structures in comparison with the expensive conventional broken-stone road subgrades.

Summary: It has been determined, the waste dumps of Lebedinsky mining are presented by technogenic clay and sand raw materials of mechanogenic origin, which can be described as complex-structured polymineral polygenetic system with relic and newly formed structures, which has no counterparts among natural formations in its set of properties. It includes minerals of various genetic types (both sedimentary and metamorphogenic), which results in forming the non-conventional systems and has influence on physical and chemical processes of soil-concretes structure formation. This made it possible to determine the efficient fields of using of mechanogenic waste, taking into account the extent of technogenic transformations, as well as to work out the classification of technogenic raw, according to its transformation in the process of technogenesis.

The mechanism of technogenic materials' microstructure formation, consisting in microstructure self-organizing –regeneration (spontaneous recovery) of the initial coagulative and crystallizational microstructure, destroyed by mechanical impacts is suggested. The self-organization phenomenon is conditioned by high chemical activity, high dispersity, crystallochemical structure features and inorganic composition of clay minerals. It has been demonstrated that self-organizing of technogenic clay raw materials microstructure results in technogenic lithogenesis, which takes place in waste dumps at technogenic deposits formation.

The character of interrelation between the microstructure of initial technogenic raw material and microstructure formation processes in soil-concrete consisting in inheriting the degree of aggregation as the first stage of soil-concrete coagulatory microstructure formation is determined. Model of the soil-concrete composite's microstructure formation consists in the partial dehydration of the soil due to interaction of free water and particles of lime-containing binder, adsorbing of the binding component by clay minerals, appearing of the new formations' nucleuses on the surface of clay particles and forming of a skeletal network of a newly-formed porous matter in the voids of clay matrix.

On the base of SEM-microphotography analysis of microstructure alteration kinetics of 3 or less years old soil-concretes on the base of clay and sand technogenic raw component the formation of network out of immature X-ray amorphous matter with pronounced oolith-like component parts, connected in the form of chains, within longtime hardening periods in soil-concrete, based on sand technogenic raw was determined. It is proved during the postgenetic period in materials, based on clay technogenic raw, newly-formed crystals, having the well-pronounced shape and faceting are generated.

The period of structure decompaction and decrease of the composite strength characteristics within the postgenetic period, which amounts to 60–90 days is determined; this is conditioned by the pressure of new formations on pore walls and by the breaking of contact between structure-forming components of the system. The subsequent strength gain is connected with the secondary consolidation of the structure. The dissolved matter in the composite fills microcracks forms the enabling environment for nucleation and decrystallization results in "healing" the composite's microstructure defects. It conduces to the augmentation of strength to its maximum value (preceding its reduction) and its further growth. The variation of strength within this period amounts to 22 %.

The formulations of soil-lime mortar based on KMA clay technogenic raw (loose strip) for strengthening of road subgrades are designed. It has been shown, that the optimum amount of waste lime, added to the technogenic clayish material (LS) is 5 %, which allows obtaining the strength indices of 4,5 MPa in cement-free samples with account of technological coefficient.

A soil-concrete formulation allowing obtaining I[st] strength class, both on the base of clay and sand technogenic raw, modified with a lime-containing binder, by adding 10 % of Portland cement to a soil-lime composite is suggested. The designed formulation allowed obtaining a composite with ultimate compression strength 15,6 MPa for LS-based soil-concrete and 10 MPa for GSFW-based soil-concrete (with account of technological coefficient – 0,89 and 0,91 respectively); with freeze-proof factor of 0,81 for LS-based soil-concrete and 0,74 for GSFW-based soil-concrete; and with waterproof coefficient of 0,64 and 0,52 respectively. The formulations, designed on the base of Lebedinsky mining technogenic raw materials allow using synthesized composite for building subgrades for auto-roads of III–IV categories.

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